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(54) **Gas turbine catalytic combustor with preburner and low NOx emissions.**

(57) During low-load operating conditions, preburner combustion products are supplied with a chemical reactant to reduce NO_x. The preburner products of combustion are mixed with a hydrocarbon fuel in the presence of a combustion catalyst (34) to ignite and initiate a catalytic combustion reaction. The preburner (12) is then shut down. The fuel/air mixture supplied the catalytic reactor bed during the mid-load operating range of the turbine is sufficiently lean to produce a combustion reaction temperature too low to produce thermal NO_x. Thus, at low-load conditions, preburner combustion occurs with NO_x reduction by chemical reactant, while the catalytic combustion occurs at mid-rang operating conditions at temperatures too low to produce NO_x. For high-load operating conditions, the catalytic combustion occurs as previously described and additional lean fuel/air mixture is supplied the reaction zone whereby thermal NO_x is likewise avoided.

EP 0 453 178 A1

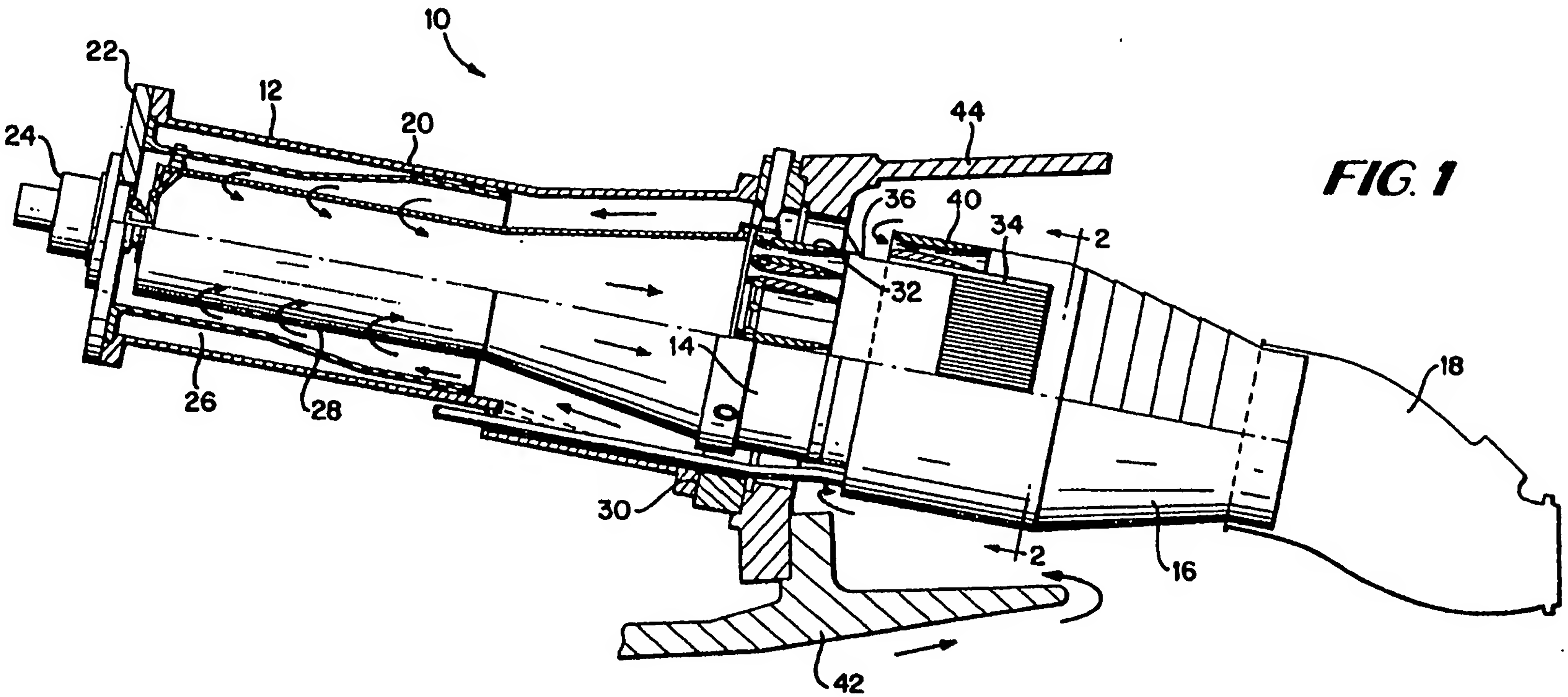


FIG. 1

The present invention relates to apparatus and methods for reducing NO_x emissions from a gas turbine and particularly relates to apparatus and m thods for reducing NO_x in a gas catalytic combustion system with preburner over the entire operating range of the gas turbine.

As set forth in our prior U.S. Patent No. 4,845,952, the objectives of many manufacturers of gas turbines include operating at high efficiency without producing undesirable air-polluting emissions. Conventional fuels normally used in gas turbines, when burned, typically produce oxides of nitrogen, carbon monoxide and unburned hydrocarbons.

NO_x compounds are produced by the reaction of nitrogen in the air at the elevated temperatures conventionally found in combustors of gas turbines. NO_x formation can be reduced by reducing maximum flame temperature in the combustor, for example, by introduction of steam. However, penalties to thermodynamic efficiency and increased capital costs are incurred. It is known to use a combustion catalyst in the reaction zone of a gas turbine combustion system to promote complete combustion of lean pre-mixed fuel and air to minimize the level of air-polluting emissions. Catalytic combustion occurs at a relatively low temperature insufficient to generate NO_x from nitrogen and oxygen reactions which occur at higher temperatures. It will be appreciated, however, that when combustor inlet air temperature and temperature rise across the combustion system are too low to support catalytic combustion, a diffusion flame preburner may be used to obtain catalytic reactor ignition. That is, catalytic combustion alone cannot be used over the entire operating range of the gas turbine because the inlet air temperature and temperature rise across the combustion system are too low to initiate and sustain pre-mixed catalytic combustion during gas turbine ignition, acceleration and operating at the low end of the gas turbine load range.

When using a diffusion flame preburner, however, significant amounts of NO_x emissions are generated. Prior catalytic combustion system designs do not include methods for reducing the preburner NO_x emission. Consequently, while low NO_x emissions are obtained over the mid-operating range of the gas turbine combustion system, prior catalytic combustions systems design do not include any method of reducing NO_x emissions from the preburner. Accordingly, a purpose of the present invention is to provide a catalytic combustion system and method of preburner NO_x abatement such that the catalytic combustion system may operate with extremely low NO_x emissions over the entire operating range of the gas turbine.

In an embodim nt of the inventi n describ d hereinafter, a catalytic combustor with a diffusion flame preburner is provided for a gas turbine system for minimizing NO_x emission through ut the operating range of th turbine. Thre different operating modes for this combustion system are provided over the load range f the gas turbine. The first operating mode is a low-load operating condition of th gas turbine wh re nly preburner combustion occurs with chemical/catalytic NO_x removal, i.e., deNO_x. For example, hydrocarbon fuel may be supplied to a preburner start-up fuel nozzle and air may be directed to a preburner combustion zone. An electrical ignition device, such as a spark or glow plug, ignites the fuel/air mixture in the preburner combustion zone with the flame being stabilized by vortex recirculation generated by swirl vanes in the start-up fuel nozzle. Significant amounts of thermal NO_x are generated by this diffusion flame reaction within the preburner combustion liner. To reduce this NO_x to molecular nitrogen and water vapor, a chemical reactant, such as ammonia, urea, isocyanic acid or the like may be injected through the primary injector for the catalytic combustion section (used during mid and high-load operating ranges) into the preburner products of combustion. Mixing may be promoted by the infusion of nitrogen with the chemical reactant. The chemical reactant may also include enhancers to accelerate the rate of reaction with NO_x from the diffusion flame preburner. The chemical reaction may occur within the catalytic reactor assembly liner and the catalytic reactor bed of the catalytic combustion zone, including the catalyst, to accelerate the deNO_x chemical reactions.

In a second operating mode characterized as a mid-load operating range for the gas turbine, catalytic combustion occurs. To achieve this, fuel is supplied by the primary injector and mixed with the preburner products of combustion. This mixture enters the catalytic reactor bed which contains a combustion catalyst, for example, palladium. This mixture of fuel and preburner products of combustion ignites in the presence of the combustion catalyst at preburner discharge temperature. Once the combustion reaction has been initiated, the preburner may be shut down, with the reaction being sustained at compressor discharge air temperature. By introducing a lean fuel/air mixture into the catalytic reactor bed, combustion reaction temperature is maintained too low to produce thermal NO_x. The hydrocarbon fuel oxidation reactions go to completion in the reaction zone within the main combustion liner. Thus, the NO_x emissions during low and mid-range operating conditions are substantially eliminated or minimized to ultra-low emissions.

At high load operating conditions for the gas turbine, a combination of catalytic and pre-mixed combustion is provided. The catalytic reactor operates in the same manner previously described as in the second p rating mode, i.e., mid-rang catalytic combustion. A secondary injector, however, is provided for mixing hydrocarbon fuel with compressor discharge air. This fuel/air mixture enters the reaction zone within th main combustion liner and is ignited by the

hot products of combustion exiting the catalytic reactor bed. Because this fuel/air mixture is lean, combustion reaction temperature is likewise too low to produce thermal NO_x. In this manner, NO_x emissions are substantially minimized or eliminated throughout the entire operating range of the gas turbine.

In a preferred embodiment according to the present invention, there is provided a method of operating a gas turbine catalytic combustion system having a preburner section and a catalytic combustion section to minimize or eliminate NO_x emissions comprising the steps of combusting a fuel/air mixture in the preburner section, reducing the NO_x resulting from the combustion of the fuel/air mixture in the preburner section, operating the preburner section to obtain catalytic reaction ignition and, upon ignition, operating the catalytic combustion section at a combustion temperature too low to produce NO_x whereby NO_x emissions from the gas turbine operation are substantially minimized or eliminated.

In a further preferred embodiment according to the present invention, there is provided a method of operating a gas turbine catalytic combustion system at low-load and mid-load ranges of gas turbine operation wherein the combustion system has a preburner section and a catalytic combustion section, comprising the steps of, at low-load operation, supplying a fuel/air mixture in the preburner section for combustion, reducing the NO_x resulting from the combustion of the fuel/air mixture in the preburner section, operating the preburner section to obtain catalytic reactor ignition in the catalytic combustion section and, upon ignition and at mid-load range, operating the catalytic combustion section with a lean fuel/air mixture such that the combustion reaction temperature is too low to produce thermal NO_x whereby NO_x emissions from gas turbine operation at low and mid-load ranges of operation are substantially minimized.

In a still further preferred embodiment according to the present invention, there is provided a gas turbine catalytic combustion system with low NO_x emissions comprising a preburner section, means for introducing fuel and air into the preburner section, an igniter in the preburner section for combusting the fuel/air mixture and means for reducing the NO_x in the products of combustion of the preburner section. A catalytic combustion section is provided having a catalytic reactor bed having a catalyst and a reaction zone. Means are provided for introducing a lean mixture of fuel and air into the catalytic combustion bed with catalytic combustion occurring at least initially from ignition by the preburner products of combustion in th presence of the catalyst in the bed. Means are also provided f r mixing compressor discharge air and fuel and supplying the mixture to the reaction zone of the combustion section for ignition by the hot products of combustion exiting the catalytic reactor bed.

In the accompanying drawings:

Figure 1 is a schematic cross-sectional illustration of a catalytic combustor forming part of a gas turbine and constructed in accordance with an exemplary embodiment of the present invention; and

Figure 2 is a cross-sectional view thereof taken generally about on line 2-2 in Figure 1.

As well known, a gas turbine includes a compressor section, a combustion section and a turbine section. The compressor section is driven by the turbine section through a common shaft connection. The combustion section typically includes a circular array of a plurality of circumferentially spaced combustors. A fuel/air mixture is burned in each combustor to produce the hot energetic flow of gas which flows through a transition piece for flowing the gas to the turbine blades of the turbine section. Thus, for purposes of the present description, only one combustor is illustrated, it being appreciated that all of the other combustors arrayed about the turbine are substantially identical to the illustrated combustor

Referring now to Figure 1, there is shown generally at 10, a combustor for a gas turbine engine and including a preburner section 12, a catalytic reactor assembly 14, a main combustion assembly 16 and a transition piece 18 for flowing hot gases of combustion to the turbine blades, not shown. The preburner assembly 12 includes a preburner casing 20, an end cover 22, a start-up fuel nozzle 24, a flow sleeve 26 and a pre-combustion liner 28 within sleeve 26. An ignition device, not shown, is provided and may comprise a spark or glow plug. Combustion in the preburner assembly 12 occurs within the combustion liner 28. Preburner combustion air directed via flow sleeve 26 enters the combustion liner 28 through a plurality of holes formed in the liner. The air enters the liner under a pressure differential across the liner and mixes with fuel from fuel nozzle 24 within the liner. Consequently, a diffusion flame combustion reaction occurs within liner 28, releasing heat for purposes of driving the gas turbine.

The catalytic combustion zone includes the reactor assembly 14 and combustion assembly 16. In that zone, there is provided an annular support ring into which hydrocarbon fuel is supplied via injector 32. For example, this might take the form of the multiple Venturi tube gas fuel injector described and illustrated in my U.S. Patent No. 4,845,952, the disclosure of which is incorporated herein by reference. Thus, the mixture of hydrocarbon fuel and preburner products of combustion enters the catalytic reactor bed 34 via the catalytic reactor assembly liner 36. The catalytic reactor bed 34 is generally cylindrical in shape and may be formed from a ceramic material or substrate of honeycombed cells coated with a reaction catalyst on their surfaces. The reaction catalyst may, for example, comprise palladium. The structure of the

catalytic reactor bed 34 may be as described and illustrated in my U.S. Patent N . 4,794,753, the disclosur of which is incorporated herein by ref rence. Thus, the mixture of fuel and preburner products of combustion ignites in the presence of the combustion catalyst at preburner discharge temperature. The fuel/air mixture entering catalytic reactor bed 34 is very lean and the hydrocarbon fuel oxidation reactions go to completion in the reaction zone within the main combustion assembly 16.

For operating at high-load conditions for the gas turbine, there is provided a secondary fuel injector 40 comprised of a plurality of Venturi tubes for mixing hydrocarbon fuel and compressor discharge air flow thereto from a plenum formed by compressor discharge casing 42 and combustion wrapper 44. This secondary fuel/air mixture enters the reaction zone 16 and is ignited by the hot products of combustion exiting the catalytic reactor bed 34.

In operation of the gas turbine, there are three distinct operating modes depending upon the load range on the gas turbine. The first operating mode is at low turbine loads and during initial start-up. In this mode, hydrocarbon fuel is supplied to start-up fuel nozzle 24 and preburner combustion air is provided liner 28 through the plurality of liner openings for mixing with the fuel from the start-up fuel nozzle. A diffusion flame combustion reaction occurs within the preburner combustion liner 28 which is initiated by a spark or glow plug. To reduce the significant amount of thermal NO_x generated in the preburner combustion liner 28, a chemical reactant, for example, ammonia, urea or isocyanic acid, is provided for injection by and through the primary injector 32. The primary injector 32 mixes the chemical reactant with the preburner products of combustion. Mixing may be promoted by using an inert carrier gas, such as nitrogen, with the chemical reactant. The chemical reactant may also include enhancers to accelerate the rate of chemical reaction with the NO_x from the diffusion flame preburner assembly. The deNO_x chemical reaction then occurs within the catalytic reactor assembly liner and the catalytic reactor bed 34 which may include a catalyst to accelerate those reactions. Consequently, significantly reduced NO_x emissions obtain from operation of the preburner at low-load operating conditions.

At mid-range operating conditions, hydrocarbon fuel is supplied injector 32. The injector 32 mixes the hydrocarbon fuel with the preburner products of combustion and this mixture enters the catalytic reactor bed 34 via the catalytic reactor assembly liner 36. The mixture of fuel and preburner products of combustion ignites in th presence f the combusti n catalyst. Onc the combustion reaction has been initiated, the preburn r may be shut down, with th reaction being sustained at compressor discharg temperatures. B cause th fuel/air mixture entering th catalytic reactor bed 34 is lean, the combustion reaction temperature is too low to produce thermal NO_x. The hydrocarbon fuel oxidati n reactions go to compl tion in the reaction zone within the main combusti n assembly liner 16. Thus, during mid-range load conditi ns, the temperature of the combustion reaction is too low to produce NO_x.

Under high-load conditions, catalytic combustion is carried on as described above. Additionally, hydrocarbon fuel is supplied the secondary injector 40. Injector 40 mixes the fuel with the compressor discharge air contained in the plenum formed between the discharge casing 42 and the combustion wrapper 44. This fuel/air mixture enters the reaction zone within the main combustion liner 16 and is ignited by the hot products of combustion exiting the catalytic reactor bed 34. Because the fuel/air mixture entering the main combustion liner 16 is lean, the combustion reaction temperature is likewise too low to produce thermal NO_x.

Consequently, it will be appreciated that NO_x emissions are substantially minimized or eliminated throughout the entire operating range of the gas turbine. This has been accomplished simply and efficiently and by a unique cooperation of essentially known gas turbine elements. Importantly, the NO_x emissions have been minimized or eliminated at the low end of the operating range, i.e., when using only the preburner. Also, it has been accomplished using elements, i.e., the primary injector, extant in gas turbines of this type.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and equivalent arrangements.

Claims

1. A method of operating a gas turbine catalytic combustion system having a preburner section and a catalytic combustion reaction to minimize or eliminate NO_x emissions comprising the steps of:

   combusting a fuel/air mixture in the preburner section;

   reducing the NO_x resulting from the combustion of the fuel/air mixture in the preburner section;

   operating the preburner section to obtain catalytic reaction ignition; and

   upon ignition, operating the catalytic combustion section at a combustion temperature too low to produce NO_x whereby NO_x emissions from said gas turbine operation are substantially minimized or eliminated.

2. A method according to Claim 1 including th step of shutting d wn the preburner combustion s c-tion once catalytic combustion occurs in the catalytic combustion chamber.

3. A method according to Claim 2 wherein the step of reducing NO_x resulting from the combustion of the fuel/air mixture in the preburner section included combining the products of combustion of the preburner section with a chemical reactant to reduce NO_x.

4. A method according to Claim 1 wherein the step of reducing NO_x resulting from the combustion of the fuel/air mixture in the preburner section includes combining the products of combustion of the preburner section with a chemical reactant to reduce NO_x.

5. A method according to Claim 4 wherein a primary fuel injector is provided for supporting combustion in the catalytic combustion section and including the further steps of introducing the chemical reactant through the primary fuel injector into the combustion products of the preburner section during preburner operation and subsequently introducing fuel through the primary fuel injector for combustion in the catalytic combustion section during catalytic combustion operation.

6. A method according to Claim 4 including catalytically accelerating the chemical reaction reducing NO_x.

7. A method according to Claim 1 including supplying a fuel/air mixture into a zone for ignition by the hot products of combustion from the catalytic combustion section at a combustion temperature too low to produce NO_x.

8. A method according to Claim 7 wherein the turbine includes a reaction zone forming part of the catalytic combustion section in which fuel oxidation reactions go to completion and a compressor having an air discharge and wherein the steps of supplying the fuel/air mixture includes combining air from the compressor discharge with fuel and injecting such fuel/air mixture into the reaction zone of the catalytic combustion section.

9. A method according to Claim 7 wherein a primary fuel injector is provided for supporting combustion in the catalytic combustion s ction and including the further steps of introducing the chemical reactant through the primary fuel injector into the combustion products of the preburner section during preburner operation and subsequently introducing fuel through the primary fuel injector for combustion in the catalytic combustion section, wherein th step of reducing NO_x resulting from the combustion of the fuel/air mixture in the preburner section includes combining the products of combustion of the preburner section with a chemical reactant to reduce NO_x.

10. A gas turbine catalytic combustion system with low NO_x emissions comprising:

a preburner section;

means for introducing fuel and air into the preburner section;

an igniter in said preburner section for combusting the fuel/air mixture;

a catalytic combustion section having a catalytic reactor bed having a catalyst and a reaction zone;

means for introducing a lean mixture of fuel and air into the catalytic combustion bed with catalytic combustion occurring at least initially from ignition by the preburner products of combustion in the presence of the catalyst in the bed;

means for mixing compressor discharge air and fuel and supplying said mixture to the reaction zone of the combustion section for ignition by the hot products of combustion exiting the catalytic reactor bed; and

means for reducing the NO_x in the producte of combustion of said preburner section, wherein said reducing means includes injector means for introducing a chemical reactant into the products of combustion of said preburner section, said means for introducing a lean mixture of fuel and air into the catalytic combustion bed also including said injector means.

FIG. 1

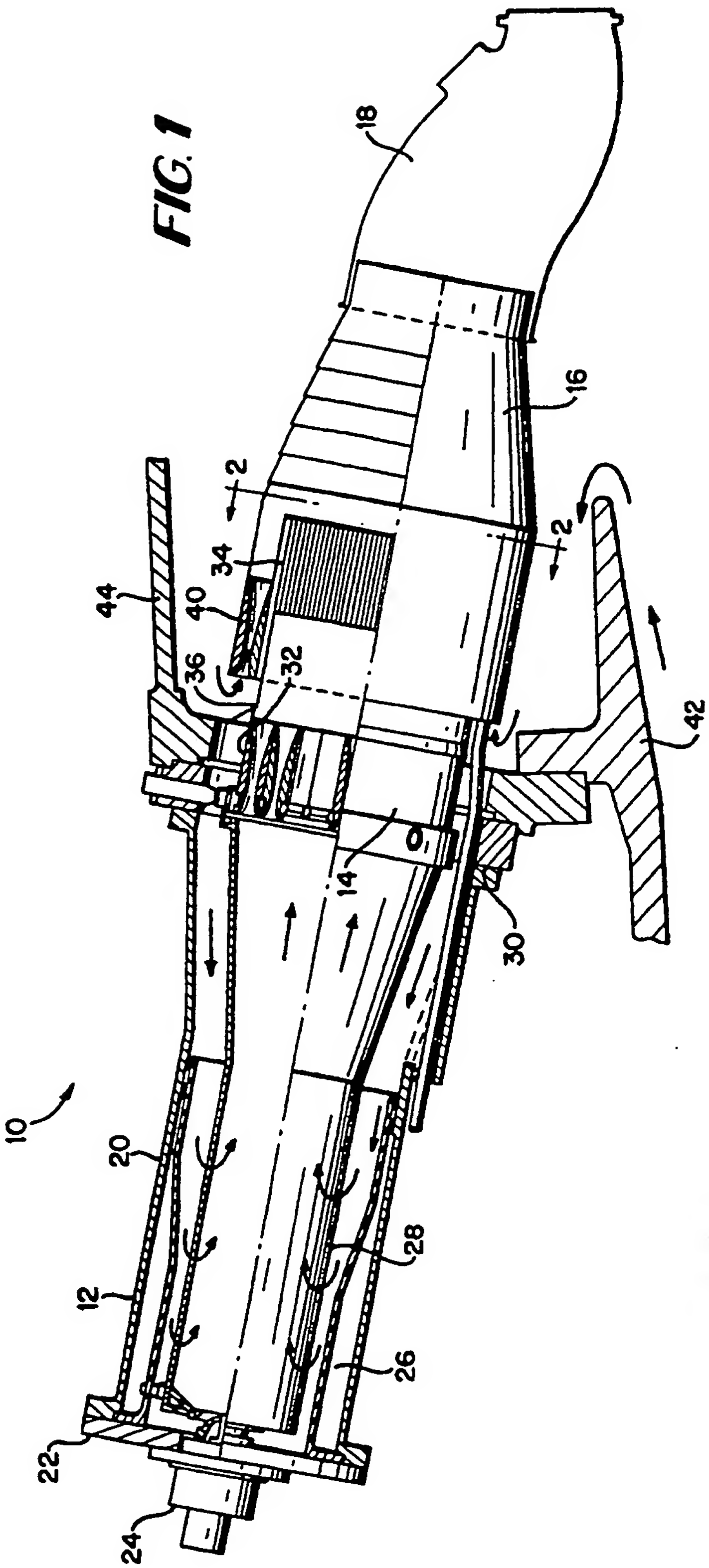
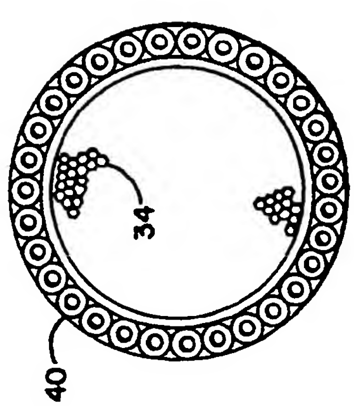


FIG. 2



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EUROPEAN SEARCH REPORT

Application Number

EP 91 30 3198

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	US-A-4825658 (K.W.BEEBE) * column 1, line 29 - column 2, line 26; figure 1 *	1-10	F23R3/40 F23R3/34 F02C3/30
Y,D	US-A-4845952 (K.W.BEEBE) * column 1, lines 29 - 43 *	1-10	
A	GB-A-2132112 (GENERAL ELECTRIC COMPANY) * abstract *	1, 10	
A	US-A-2636342 (G.N.CADE) * column 2, line 34 - column 3, line 3 *	1, 10	
A	EP-A-62149 (WESTINGHOUSE ELECTRIC CORPORATION)		
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			F23R F02C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24 JUNE 1991	CRIADO Y JIMENEZ, F.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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(56) References cited :
EP-A- 0 062 149
GB-A- 2 132 112
US-A- 2 636 342
US-A- 4 825 658
US-A- 4 845 952

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EP 0 453 178 B1

Descripti n

The present invention relates to apparatus and methods for reducing NO_x emissions from a gas turbine and particularly relates to apparatus and methods for reducing NO_x in a gas catalytic combustion system with preburner over the entire operating range of the gas turbine.

As set forth in our prior U.S. Patent No. 4,845,952, the objectives of many manufacturers of gas turbines include operating at high efficiency without producing undesirable air-polluting emissions. Conventional fuels normally used in gas turbines, when burned, typically produce oxides of nitrogen, carbon monoxide and unburned hydrocarbons.

NO_x compounds are produced by the reaction of nitrogen in the air at the elevated temperatures conventionally found in combustors of gas turbines. NO_x formation can be reduced by reducing maximum flame temperature in the combustor, for example, by introduction of steam. However, penalties to thermodynamic efficiency and increased capital costs are incurred. It is known to use a combustion catalyst in the reaction zone of a gas turbine combustion system to promote complete combustion of lean pre-mixed fuel and air to minimize the level of air-polluting emissions. Catalytic combustion occurs at a relatively low temperature insufficient to generate NO_x from nitrogen and oxygen reactions which occur at higher temperatures. It will be appreciated, however, that when combustor inlet air temperature and temperature rise across the combustion system are too low to support catalytic combustion, a diffusion flame preburner may be used to obtain catalytic reactor ignition. That is, catalytic combustion alone cannot be used over the entire operating range of the gas turbine because the inlet air temperature and temperature rise across the combustion system are too low to initiate and sustain pre-mixed catalytic combustion during gas turbine ignition, acceleration and operating at the low end of the gas turbine load range.

When using a diffusion flame preburner, however, significant amounts of NO_x emissions are generated. Prior catalytic combustion system designs do not include methods for reducing the preburner NO_x emission. Consequently, while low NO_x emissions are obtained over the mid-operating range of the gas turbine combustion system, prior catalytic combustions systems design do not include any method of reducing NO_x emissions from the preburner.

US-A-4825658 discloses a fuel nozzle for providing fuel to the preburner section, wherein the nozzle includes an igniter assembly including a coil coated with a catalyst material promoting ignition/combustion under low fuel/h at r lease conditions. This a r l-ativ ly compl x arrangement for d aling with th low temperature operating rang .

US-A-2636342 discloses the introduction of a non gaseous nitrogen compound into the combustion zone of a jet engine t giv larg volumes of gas, with a view to stabilizing th burning of the fuel. However this disclosure is not concerned with reducing NO_x emissions.

Accordingly, a purpose of the present invention is to provide a catalytic combustion system and method of preburner NO_x abatement such that the catalytic combustion system may operate with extremely low NO_x emissions over the entire operating range of the gas turbine.

In one aspect the present invention provides a method of operating a gas turbine catalytic combustion system having a preburner section and a catalytic combustion section to minimize or eliminate NO_x emissions comprising the steps of combusting a fuel/air mixture in the preburner section; reducing the NO_x resulting from the combustion of the fuel/air mixture in the preburner section by combining the products of combustion of the preburner section with a chemical reactant to reduce NO_x at an operating condition where products of combustion of the preburner section are at a temperature too low for catalytic combustion; operating the preburner section to obtain catalytic reaction ignition; and upon ignition, operating the catalytic combustion section at a combustion temperature too low to produce NO_x whereby NO_x emissions from said gas turbine operation are substantially minimized or eliminated.

In a further aspect the present invention provides a gas turbine catalytic combustion system with low NO_x emissions comprising a preburner section; means for introducing fuel and air into the preburner section; an igniter in said preburner section for combusting the fuel/air mixture; a catalytic combustion section having a catalytic reactor bed having a catalyst and a reaction zone; means for introducing a lean mixture of fuel and air into the catalytic combustion bed with catalytic combustion occurring at least initially from ignition by the preburner products of combustion in the presence of the catalyst in the bed; and means for mixing compressor discharge air and fuel and supplying said mixture to the reaction zone of the combustion section for ignition by the hot products of combustion exiting the catalytic reactor bed; characterized in that means are provided in the preburner section for reducing the NO_x in the products of combustion of said preburner section, wherein said reducing means includes injector means for introducing a chemical reactant into the products of combustion of said preburner section, said means for introducing a lean mixture of fuel and air into the catalytic combustion bed also including said injector means.

In an mbodiment of the invention d scribed hereinaft r, a catalytic combustor with a diffusion flam pr burner is provided for a gas turbin system for minimizing NO_x emission throughout the operating range of the turbin . Thre different operating modes

for this combustion system are provided over the load range of the gas turbine. The first operating mod is a low-load operating condition of th gas turbine wher only preburner combustion occurs with chemical/catalytic NO_x removal, i.e., $deNO_x$. For example, hydrocarbon fuel may be supplied to a preburner start-up fuel nozzle and air may be directed to a preburner combustion zone. An electrical ignition device, such as a spark or glow plug, ignites the fuel/air mixture in the preburner combustion zone with the flame being stabilized by vortex recirculation generated by swirl vanes in the start-up fuel nozzle. Significant amounts of thermal NO_x are generated by this diffusion flame reaction within the preburner combustion liner. To reduce this NO_x to molecular nitrogen and water vapor, a chemical reactant, such as ammonia, urea, isocyanic acid or the like may be injected through the primary injector for the catalytic combustion section (used during mid and high-load operating ranges) into the preburner products of combustion. Mixing may be promoted by the infusion of nitrogen with the chemical reactant. The chemical reactant may also include enhancers to accelerate the rate of reaction with NO_x from the diffusion flame preburner. The chemical reaction may occur within the catalytic reactor assembly liner and the catalytic reactor bed of the catalytic combustion zone, including the catalyst, to accelerate the $deNO_x$ chemical reactions.

In a second operating mode characterized as a mid-load operating range for the gas turbine, catalytic combustion occurs. To achieve this, fuel is supplied by the primary injector and mixed with the preburner products of combustion. This mixture enters the catalytic reactor bed which contains a combustion catalyst, for example, palladium. This mixture of fuel and preburner products of combustion ignites in the presence of the combustion catalyst at preburner discharge temperature. Once the combustion reaction has been initiated, the preburner may be shut down, with the reaction being sustained at compressor discharge air temperature. By introducing a lean fuel/air mixture into the catalytic reactor bed, combustion reaction temperature is maintained too low to produce thermal NO_x. The hydrocarbon fuel oxidation reactions go to completion in the reaction zone within the main combustion liner. Thus, the NO_x emissions during low and mid-range operating conditions are substantially eliminated or minimized to ultra-low emissions.

At high load operating conditions for the gas turbine, a combination of catalytic and pre-mixed combustion is provided. The catalytic reactor operates in the same manner previously described as in the second operating mode, i.e., mid-range catalytic combustion. A secondary injector, however, is provided for mixing hydrocarbon fuel with compressor discharg air. This fuel/air mixture enters th reaction zone within th main combustion liner and is ignited by the hot products of combustion exiting the catalytic reactor bed. Because this fuel/air mixture is lean, combustion reaction temperatur is likewise too low to produce thermal NO_x. In this manner, NO_x emissions are substantially minimized or eliminated throughout the entire operating range of the gas turbine.

In a preferred embodiment according to the present invention, there is provided a method of operating a gas turbine catalytic combustion system having a preburner section and a catalytic combustion section to minimize or eliminate NO_x emissions comprising the steps of combusting a fuel/air mixture in the preburner section, reducing the NO_x resulting from the combustion of the fuel/air mixture in the preburner section, operating the preburner section to obtain catalytic reaction ignition and, upon ignition, operating the catalytic combustion section at a combustion temperature too low to produce NO_x whereby NO_x emissions from the gas turbine operation are substantially minimized or eliminated.

In a further preferred embodiment according to the present invention, there is provided a method of operating a gas turbine catalytic combustion system at low-load and mid-load ranges of gas turbine operation wherein the combustion system has a preburner section and a catalytic combustion section, comprising the steps of, at low-load operation, supplying a fuel/air mixture in the preburner section for combustion, reducing the NO_x resulting from the combustion of the fuel/air mixture in the preburner section, operating the preburner section to obtain catalytic reactor ignition in the catalytic combustion section and, upon ignition and at mid-load range, operating the catalytic combustion section with a lean fuel/air mixture such that the combustion reaction temperature is too low to produce thermal NO_x whereby NO_x emissions from gas turbine operation at low and mid-load ranges of operation are substantially minimized.

In a still further preferred embodiment according to the present invention, there is provided a gas turbine catalytic combustion system with low NO_x emissions comprising a preburner section, means for introducing fuel and air into the preburner section, an igniter in the preburner section for combusting the fuel/air mixture and means for reducing the NO_x in the products of combustion of the preburner section. A catalytic combustion section is provided having a catalytic reactor bed having a catalyst and a reaction zone. Means are provided for introducing a lean mixture of fuel and air into the catalytic combustion bed with catalytic combustion occurring at least initially from ignition by the preburner products of combustion in the presence of the catalyst in the bed. Means are also provided for mixing compressor discharge air and fuel and supplying th mixture to the reaction zon of the combustion section for ignition by the hot products of combustion xiting the catalytic reactor bed.

In the accompanying drawings:

Figure 1 is a schematic cross-sectional illustration of a catalytic combustor forming part of a gas turbine and constructed in accordance with an exemplary embodiment of the present invention; and

Figure 2 is a cross-sectional view thereof taken generally about on line 2-2 in Figure 1.

As well known, a gas turbine includes a compressor section, a combustion section and a turbine section. The compressor section is driven by the turbine section through a common shaft connection. The combustion section typically includes a circular array of a plurality of circumferentially spaced combustors. A fuel/air mixture is burned in each combustor to produce the hot energetic flow of gas which flows through a transition piece for flowing the gas to the turbine blades of the turbine section. Thus, for purposes of the present description, only one combustor is illustrated, it being appreciated that all of the other combustors arrayed about the turbine are substantially identical to the illustrated combustor.

Referring now to Figure 1, there is shown generally at 10, a combustor for a gas turbine engine and including a preburner section 12, a catalytic reactor assembly 14, a main combustion assembly 16 and a transition piece 18 for flowing hot gases of combustion to the turbine blades, not shown. The preburner assembly 12 includes a preburner casing 20, an end cover 22, a start-up fuel nozzle 24, a flow sleeve 26 and a pre-combustion liner 28 within sleeve 26. An ignition device, not shown, is provided and may comprise a spark or glow plug. Combustion in the preburner assembly 12 occurs within the combustion liner 28. Preburner combustion air directed via flow sleeve 26 enters the combustion liner 28 through a plurality of holes formed in the liner. The air enters the liner under a pressure differential across the liner and mixes with fuel from fuel nozzle 24 within the liner. Consequently, a diffusion flame combustion reaction occurs within liner 28, releasing heat for purposes of driving the gas turbine.

The catalytic combustion zone includes the reactor assembly 14 and combustion assembly 16. In that zone, there is provided an annular support ring into which hydrocarbon fuel is supplied via injector 32. For example, this might take the form of the multiple Venturi tube gas fuel injector described and illustrated in my U.S. Patent No. 4,845,952, the disclosure of which is incorporated herein by reference. Thus, the mixture of hydrocarbon fuel and preburner products of combustion enters the catalytic reactor bed 34 via the catalytic reactor assembly liner 36. The catalytic reactor b d 34 is generally cylindrical in shape and may be formed from a ceramic material or substrate of honeycombed cells coated with a reaction catalyst on their surfaces. The reaction catalyst may, for xample, compris palladium. Th structur of the catalytic reactor bed 34 may b as described and illustrated in my U.S. Patent No. 4,794,753, the disclosure f which is incorporated herein by reference. Thus, the mixture of fuel and preburner products of combustion ignites in the presence of the combustion catalyst at preburner discharge temperature. The fuel/air mixture entering catalytic reactor bed 34 is very lean and the hydrocarbon fuel oxidation reactions go to completion in the reaction zone within the main combustion assembly 16.

For operating at high-load conditions for the gas turbine, there is provided a secondary fuel injector 40 comprised of a plurality of Venturi tubes for mixing hydrocarbon fuel and compressor discharge air flow thereto from a plenum formed by compressor discharge casing 42 and combustion wrapper 44. This secondary fuel/air mixture enters the reaction zone 16 and is ignited by the hot products of combustion exiting the catalytic reactor bed 34.

In operation of the gas turbine, there are three distinct operating modes depending upon the load range on the gas turbine. The first operating mode is at low turbine loads and during initial start-up. In this mode, hydrocarbon fuel is supplied to start-up fuel nozzle 24 and preburner combustion air is provided liner 28 through the plurality of liner openings for mixing with the fuel from the start-up fuel nozzle. A diffusion flame combustion reaction occurs within the preburner combustion liner 28 which is initiated by a spark or glow plug. To reduce the significant amount of thermal NO_x generated in the preburner combustion liner 28, a chemical reactant, for example, ammonia, urea or isocyanic acid, is provided for injection by and through the primary injector 32. The primary injector 32 mixes the chemical reactant with the preburner products of combustion. Mixing may be promoted by using an inert carrier gas, such as nitrogen, with the chemical reactant. The chemical reactant may also include enhancers to accelerate the rate of chemical reaction with the NO_x from the diffusion flame preburner assembly. The deNO_x chemical reaction then occurs within the catalytic reactor assembly liner and the catalytic reactor bed 34 which may include a catalyst to accelerate those reactions. Consequently, significantly reduced NO_x emissions obtain from operation of the preburner at low-load operating conditions.

At mid-range operating conditions, hydrocarbon fuel is supplied injector 32. The injector 32 mixes the hydrocarbon fuel with the preburner products of combustion and this mixture enters the catalytic reactor bed 34 via the catalytic reactor assembly liner 36. The mixture of fuel and preburner products of combustion ignites in th presenc of the combustion catalyst. Once th combusti n reaction has b en initiated, the preburner may b shut down, with the reaction being sustained at compressor discharg temp ratures. Because the fuel/air mixture entering the catalytic re-

actor bed 34 is lean, the combustion reaction temperature is too low to produce thermal NO_x. The hydrocarbon fuel oxidation reactions go to completion in the reaction zone within the main combustion assembly liner 16. Thus, during mid-range load conditions, the temperature of the combustion reaction is too low to produce NO_x.

Under high-load conditions, catalytic combustion is carried on as described above. Additionally, hydrocarbon fuel is supplied the secondary injector 40. Injector 40 mixes the fuel with the compressor discharge air contained in the plenum formed between the discharge casing 42 and the combustion wrapper 44. This fuel/air mixture enters the reaction zone within the main combustion liner 16 and is ignited by the hot products of combustion exiting the catalytic reactor bed 34. Because the fuel/air mixture entering the main combustion liner 16 is lean, the combustion reaction temperature is likewise too low to produce thermal NO_x.

Consequently, it will be appreciated that NO_x emissions are substantially minimized or eliminated throughout the entire operating range of the gas turbine. This has been accomplished simply and efficiently and by a unique cooperation of essentially known gas turbine elements. Importantly, the NO_x emissions have been minimized or eliminated at the low end of the operating range, i.e., when using only the preburner. Also, it has been accomplished using elements, i.e., the primary injector, extant in gas turbines of this type.

Claims

1. A method of operating a gas turbine catalytic combustion system having a preburner section (12) and a catalytic combustion section (34) to minimize or eliminate NO_x emissions comprising the steps of:

   combusting a fuel/air mixture in the preburner section (12);

   reducing the NO_x resulting from the combustion of the fuel/air mixture in the preburner section by combining the products of combustion of the preburner section with a chèmical reactant to reduce NO_x at an operating condition where products of combustion of the preburner section are at a temperature too low for catalytic combustion;

   operating the preburner section to obtain catalytic reaction ignition; and

   upon ignition, operating the catalytic combustion section (34) at a combustion t mperatur too low to produce NO_x wh r by NO_x emissions from said gas turbine operation are substantially minimized or eliminated.

2. A method according to claim 1 including the step of shutting down the preburner combustion section onc catalytic combustion occurs in the catalytic combustion chamber.

3. A method according to claim 1 wherein a primary fuel injection (32) is provided for supporting combustion in the catalytic combustion section and including the further steps of introducing the chemical reactant through the primary fuel injector into the combustion products of the preburner section during preburner operation and subsequently introducing fuel through the primary fuel injector for combustion in the catalytic combustion section during catalytic combustion operation.

4. A method according to claim 1 including catalytically accelerating the chemical reaction reducing NO_x.

5. A method according to claim 1 including supplying a fuel/air mixture into a zone (16) for ignition by the hot products of combustion from the catalytic combustion section at a combustion temperature too low to produce NO_x.

6. A method according to claim 5 wherein the turbine includes a reaction zone (14) forming part of the catalytic combustion section in which fuel oxidation reactions go to completion and compressor having an air discharge and wherein the steps of supplying the fuel/air mixture includes combining air from the compressor discharge with fuel (40) and injecting such fuel /air mixture into the reaction zone of the catalytic combustion section.

7. A method according to claim 5 wherein a primary fuel injector (32) is provided for supporting combustion in the catalytic combustion section and including the further steps of introducing the chemical reactant through the primary fuel injector into the combustion products of the preburner section during preburner operation and subsequently introducing fuel through the primary fuel injector for combustion in the catalytic combustion section, wherein the step of reducing NO_x resulting from the combustion of the fuel/air mixture in the preburner section includes combining the products of combustion of the preburner section with a chemical reactant to reduce NO_x.

8. A gas turbine catalytic combustion system with low NO_x emissions comprising:

   a preburner s ction (12);

   means for introducing fuel and air (24,28) into the preburner section;

   an igniter in said preburner section for

combusting the fuel/air mixture;

a catalytic combustion section (14) having a catalytic r actor bed (34) having a catalyst and a reaction zone;

means (32,36) for introducing a lean mixture of fuel and air into the catalytic combustion bed with catalytic combustion occurring at least initially from ignition by the preburner products of combustion in the presence of the catalyst in the bed; and

means for mixing compressor discharge air and fuel (36,40) and supplying said mixture to the reaction zone of the combustion section for ignition by the hot products of combustion exiting the catalytic reactor bed;

characterized in that means are provided in the preburner section for reducing the NO_x in the products of combustion of said preburner section, wherein said reducing means includes injector means (32) for introducing a chemical reactant into the products of combustion of said preburner section, said means for introducing a lean mixture of fuel and air into the catalytic combustion bed also including said injector means.

Patentansprüche

1. Verfahren zum Betreiben eines katalytischen Verbrennungssystems einer Gasturbine mit einem Vorbrennerabschnitt (12) und einem katalytischen Verbrennungsabschnitt (34) zum Minimieren oder Eliminieren von NO_x Emissionen, enthaltend die Schritte:

   Verbrennen eines Brennstoff/Luft-Gemisches in dem Vorbrennerabschnitt (12),

   Reduzieren der NO_x, die aus der Verbrennung des Brennstoff/Luft-Gemisches in dem Vorbrennerabschnitt entstehen, durch Vereinigen der Verbrennungsprodukte des Vorbrennerabschnitts mit einem chemischen Verbrennungshilfsstoff zum Reduzieren von NO_x bei einem Betriebszustand, wo Verbrennungsprodukte des Vorbrennerabschnitts auf einer für eine katalytische Verbrennung zu niedrigen Temperatur sind,

   Betreiben des Vorbrennerabschnitts, um eine Zündung der katalytischen Reaktion zu erhalten, und

   bei Zündung, Betreiben des katalytischen Verbrennungsabschnitts (34) bei einer Verbrennungstemperatur, die für eine Erzeugung von NO_x zu niedrig ist, wodurch NO_x Emissionen aus dem Gasturbinenbetrieb im wesentlichen minimiert od r eliminiert werden.

2. Verfahren nach Anspruch 1, wobei der Vorbrennerabschnitt abgeschaltet wird, wenn die katalytisch Verbrennung in der katalytischen Brennkammer auftritt.

3. Verfahren nach Anspruch 1, wobei ine primäre Brennstoffinjektion (32) vorgesehen ist zum Unterhalten einer Verbrennung in dem katalytischen Verbrennungsabschnitt, und der chemische Verbrennungshilfsstoff durch den primären Brennstoffinjektor in die Verbrennungsprodukte während des Vorbrennerbetriebs eingeführt wird und anschließend Brennstoff durch den primären Brennstoffinjektor eingeführt wird für eine Verbrennung in dem katalytischen Verbrennungsabschnitt während des katalytischen Verbrennungsvorgangs.

4. Verfahren nach Anspruch 1, wobei die NO_x reduzierende chemische Reaktion katalytisch beschleunigt wird.

5. Verfahren nach Anspruch 1, wobei ein Brennstoff/Luft-Gemisch einer Zone (16) zugeführt wird für eine Zündung durch die heißen Verbrennungsprodukte aus dem katalytischen Verbrennungsabschnitt bei einer Verbrennungstemperatur, die zur Erzeugung von NO_x zu niedrig ist.

6. Verfahren nach Anspruch 5, wobei die Turbine eine Reaktionszone (14), die einen Teil des katalytischen Verbrennungsabschnitts bildet, in dem Brennstoffoxidationsreaktionen abgeschlossen werden, und einen Verdichter mit einem Luftausgang aufweist, und wobei in dem Schritt des Zuführens des Brennstoff/Luft-Gemisches Luft aus dem Verdichterausgang mit Brennstoff (40) gemischt wird und dieses Brennstoff/Luft-Gemisch in die Reaktionszone des katalytischen Verbrennungsabschnitts injiziert wird.

7. Verfahren nach Anspruch 5, wobei ein primärer Brennstoffinjektor (32) zur Unterhaltung einer Verbrennung in dem katalytischen Verbrennungsabschnitt vorgesehen ist und ein chemischer Verbrennungshilfsstoff durch den primären Brennstoffinjektor in die Verbrennungsprodukte des Vorbrennerabschnitts während des Vorbrennerbetriebs eingeführt wird und anschließend Brennstoff durch den primären Brennstoffinjektor eingeführt wird für eine Verbrennung in dem katalytischen Verbrennungsabschnitt, wobei in dem Schritt des Reduzierens von NO_x, die aus der Verbrennung des Brennstoff/Luft-Gemisches in dem Vorbrennerabschnitt resultieren, die Verbrennungsprodukte des Vorbrennerabschnitts mit inem chemischen Verbrennungshilfsstoff gemischt w rden, um NO_x zu reduzieren.

8. Katalytisches Gasturbinen-Verbrennungssystem mit geringen NO_x Emissionen, enthalt nd:

einen Vorbrennerabschnitt (12),

eine Einrichtung zum Einführen von Brennstoff und Luft (24,28) in den Vorbrennerabschnitt,

eine Zündeinrichtung in dem Vorbrennerabschnitt zum Verbrennen des Brennstoff/Luft-Gemisches,

einen katalytischen Verbrennungsabschnitt (14) mit einem katalytischen Reaktorbett (34) mit einem Katalysator und einer Reaktionszone,

eine Einrichtung (32,36) zum Einführen eines mageren Gemisches von Brennstoff und Luft in das katalytische Verbrennungsbett, wobei eine katalytische Verbrennung wenigstens zunächst auftritt durch eine Zündung durch die Verbrennungsprodukte des Vorbrenners in Gegenwart des Katalysators in dem Bett, und

eine Einrichtung zum Mischen von Verdichterausgangsluft und Brennstoff (36,40) und zum Zuführen des Gemisches in die Reaktionszone des Verbrennungsabschnitts für eine Zündung durch die heißen Verbrennungsprodukte, die aus dem katalytischen Reaktorbett austreten,

dadurch gekennzeichnet, daß in dem Vorbrennerabschnitt Mittel vorgesehen sind zum Reduzieren der NO_x in den Verbrennungsprodukten des Vorbrennerabschnitts, wobei die Reduziermittel eine Injektoreinrichtung (32) zum Einführen eines chemischen Verbrennungshilfsstoffes in die Verbrennungsprodukte des Vorbrennerabschnitts aufweisen und wobei die Einrichtung zum Einführen eines mageren Gemisches von Brennstoff und Luft in das katalytische Verbrennungsbett auch die Injektoreinrichtung enthält.

Revendications

1. Procédé de fonctionnement pour un système de combustion catalytique de turbine à gaz possédant une section de pré-brûleur (12) et une section de combustion catalytique (34) pour minimiser ou éliminer les émissions de NO_x, comportant les étapes suivantes :

   la combustion d'un mélange combustible/air dans la section de pré-brûleur (12) ;

   la réduction du NO_x résultant de la combustion du mélange combustible/air dans la section de pré-brûleur en combinant les produits de combustion de la section de pré-brûleur avec un réactif chimique afin de réduire le NO_x sous des conditions de fonctionnement dans lesquelles les produits de combustion de la section de pré-brûleur sont à une t mpérature trop bass pour la combustion catalytiqu ;

   le fonctionn ment de la s ction d pré-brûleur pour obtenir l'amorçage de la réaction catalytique ; et

   lors de l'amorçage, le fonctionnement de la section de combustion catalytique (34) à un température de combustion trop basse pour produire du NO_x, grâce à quoi les émissions de NO_x dudit fonctionnement de la turbine à gaz sont substantiellement minimisées ou éliminées.

2. Procédé selon la revendication 1, comportant l'étape d'extinction de la section de combustion du pré-brûleur lorsque la combustion catalytique se produit dans la chambre de combustion catalytique.

3. Procédé selon la revendication 1, dans lequel une injection de combustible primaire (32) est effectuée pour maintenir la combustion dans la section de combustion catalytique, et comportant les étapes additionnelles d'introduction du réactif chimique par l'injecteur de combustible primaire dans les produits de combustion de la section de pré-brûleur durant le fonctionnement du pré-brûleur, puis d'introduction de combustible par l'injecteur de combustible primaire pour la combustion dans la section de combustion catalytique durant l'opération de combustion catalytique.

4. Procédé selon la revendication 1, comportant l'accélération catalytique de la réaction chimique réduisant le NO_x.

5. Procédé selon la revendication 1, comportant la délivrance d'un mélange combustible/air dans une zone (16) pour l'allumage par les produits de combustion chauds issus de la section de combustion catalytique à une température de combustion trop basse pour produire du NO_x.

6. Procédé selon la revendication 5, dans lequel la turbine comporte une zone de réaction (14) faisant partie de la section de combustion catalytique, dans laquelle les réactions d'oxydation du combustible vont jusqu'à leur achèvement, et un compresseur ayant une décharge d'air, et dans lequel les étapes de délivrance du mélange combustible/air comprennent la combinaison de l'air provenant de la décharge du compresseur avec du combustible (40) et l'injection de ce mélange combustible/air dans la zone de réaction de la section de combustion catalytique.

7. Procédé selon la revendication 5, dans lequel un injecteur de combustible primaire (32) est disposé pour maintenir la combustion dans la section de combustion catalytiqu , t comportant les étapes additionnelles d'introduction du réactif chimique par l'injecteur de combustibl primaire dans les produits de combustion de la section de pré-

brûleur durant le fonctionnement du pré-brûleur, puis d'introduction de combustible par l'injecteur de combustible primair pour la combustion dans la section de combustion catalytique, dans lequel l'étape de réduction du NO_x résultant de la combustion du mélange combustible/air dans la section de pré-brûleur comprend la combinaison des produits de combustion de la section de pré-brûleur avec un réactif chimique afin de réduire le NO_x.

8. Système de combustion catalytique de turbine à gaz à faibles émissions de NO_x, comportant :

   une section de pré-brûleur (12) ;

   des moyens pour introduire du combustible et de l'air (24, 28) dans la section de pré-brûleur ;

   un dispositif d'allumage dans ladite section de pré-brûleur pour provoquer la combustion du mélange combustible/air ;

   une section de combustion catalytique (14) possédant un lit de réacteur catalytique (34) ayant un catalyseur et une zone de réaction ;

   des moyens (32, 36) pour introduire un mélange pauvre de combustible et d'air dans le lit de combustion catalytique, la combustion catalytique se produisant au moins initialement sous l'effet de l'allumage par les produits de combustion du pré-brûleur en présence du catalyseur dans le lit ; et

   des moyens pour mélanger l'air de décharge du compresseur et le combustible (36, 40) et pour délivrer ledit mélange à la zone de réaction de la section de combustion pour l'allumage par les produits de combustion chauds qui quittent le lit de réacteur catalytique ;

   caractérisé en ce que des moyens sont disposés dans la section de pré-brûleur pour réduire le NO_x dans les produits de combustion de ladite section de pré-brûleur, dans lesquels lesdits moyens de réduction comportent des moyens formant injecteur (32) pour introduire un réactif chimique dans les produits de combustion de ladite section de pré-brûleur, lesdits moyens pour introduire un mélange pauvre de combustible et d'air dans le lit de combustion catalytique comportant également lesdits moyens formant injecteur.

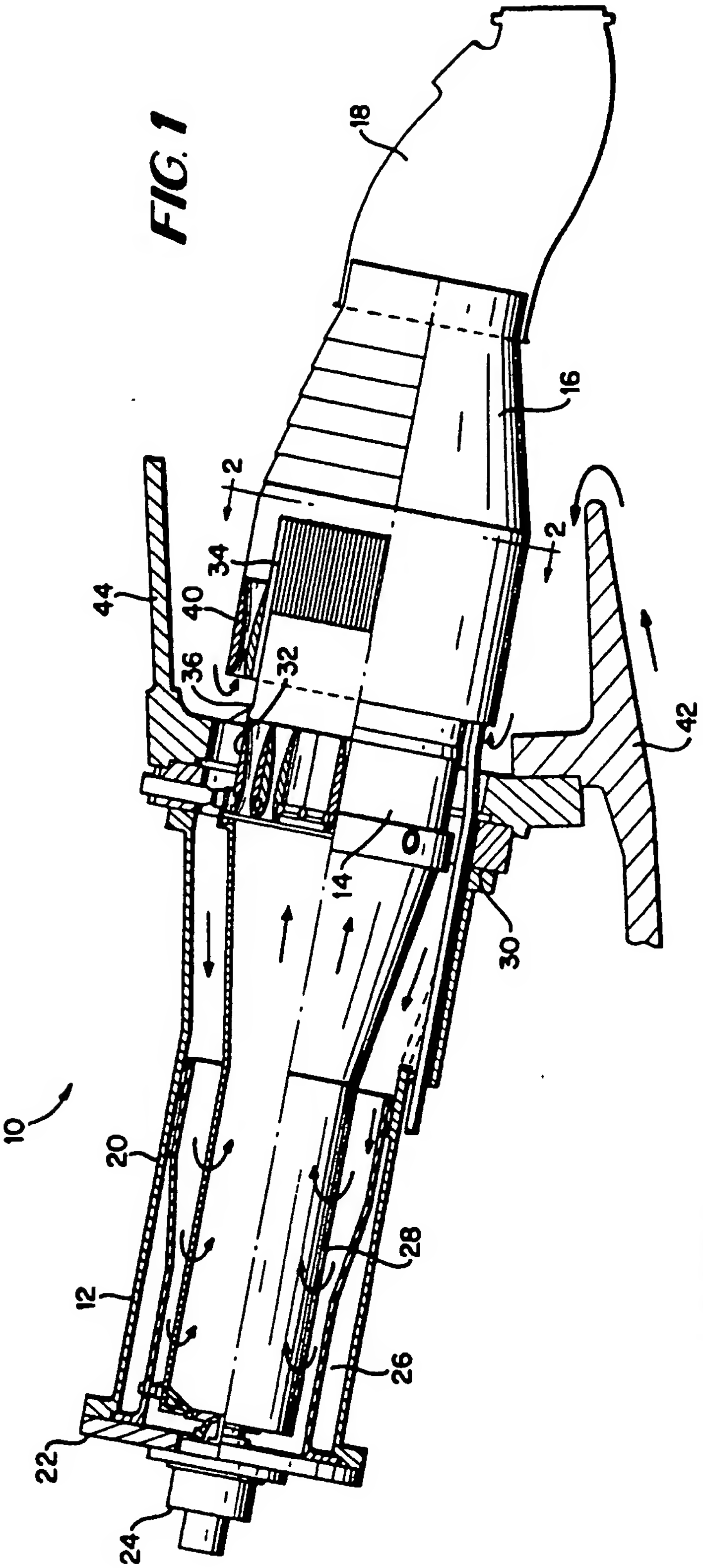

FIG. 1

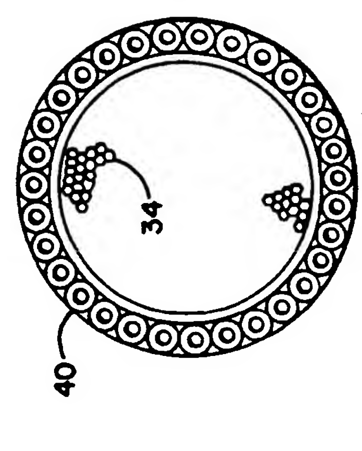

FIG. 2